and for the factories, 63. As before, the country air is distinctly freer from microbic life than the atmosphere of the city, although a single high value for the country brings their general averages close together. The factory air is higher in content than any other group, so far as the general distribution of results is concerned. The office samples, as before, show many very low and a few very high counts, the latter bringing the average up above even that for factories.

The ratio of the 37°-count to the 20°-count was about 1 to 1.9 for country air, 1 to 2.4 for city air, 1 to 1.2 for the offices, and 1 to 1.8 for the factories. All these ratios are high in comparison with those we find in water of good quality.

Finally, we made an estimate of the number of mouth streptococci present by isolating pure cultures from any colonies characteristic of this group upon the litmus-lactose-agar plates and studying their morphology and fermentation reactions. The lactose fermenting organisms when found in air appear to be chiefly derived from the human mouth and to be reasonably good indices of mouth pollution of the atmosphere. The results of this study are indicated in Table 3 with a summary of the 20° and 37° averages previously discussed.

TABLE 3.—*Average microbic content of the air from various sources.*

Samples.		Microbes per cubic foot.		Streptococci per 100 cubic feet.
Source.	Number.	20° C.	37° C.	
Country	85	56	30	12
City	134	72	32	11
Offices	87	94	80	22
Factories	47	113	63	43
Schools	684	96	....	30

So far as the presence of mouth streptococci is concerned, there is a clear distinction between outdoor and indoor air, the former having less than half as many streptococci as the latter, while the factory air is more polluted than the air of the offices and schools.

Conclusions.

In general it may be concluded from this survey of the microbic content of 353 samples of air from various sources that:

1. The number of microbes developing at 20° C. from outdoor air in suburban districts is generally under 50 per cubic foot and rarely over 100.

The count at 37° C. for such air is about half that at 20° C. and rarely over 50 per cubic foot. The number of mouth streptococci in such air is small—in the neighborhood of 10 per 100 cubic feet. The air from more remote regions would no doubt show still smaller numbers.

2. The air of city streets shows a slightly higher number of microbes, but the general relations are much the same in all the respects noted above.

3. The air of occupied spaces shows, as might be expected, larger average numbers of bacteria and much greater fluctuations. The 20°-count may average over 100 microbes per cubic foot, as in the factories studied, and may reach 700 or more, as in some of the offices. The 37°-count averaged over 50 both in factories and offices and was nearly as high as the 20°-count in the latter case. A few very high 37°-counts were obtained, two between 1,000 and 2,000 in offices, and one of 5,200 in the country, the latter clearly abnormal. Mouth streptococci are much more abundant in indoor air, ranging from 20 to 40 per 100 cubic feet of air, and the results bear out the conclusion that the number of these organisms furnishes a good measure of mouth pollution due to concentration of population in confined spaces.

THEORETICAL METEOROLOGY: MORE PARTICULARLY THE THERMODYNAMICS OF THE ATMOSPHERE.

[Communicated to the International Meteorological Congress at Chicago, Ill., August, 1893.]

By PROF. DR. WILHELM VON BEZOLD.

[Dated: Kgl. Preussisches Meteorologisches Institut, Berlin, July 12, 1893.]

[The late Wilhelm von Bezold was born June 21, 1837, at Munich, and died at Berlin on February 17, 1907, at the age of 69. At the time of his death he was director of the Royal Prussian Meteorological Institute and professor of meteorology in the University of Berlin, a position he had held since 1885. From 1868 to 1885 he was professor of physics in the Technische Hochschule at Munich, Bavaria, where he had also been actively engaged from 1879 to 1885 in organizing and directing the Bavarian meteorological réseau and service. A brief notice of his work is given in the MONTHLY WEATHER REVIEW for February, 1907, 35:73.

The present paper was prepared for publication between 1901 and 1912, but publication has been delayed for the reasons stated in the MONTHLY WEATHER REVIEW for February, 1914, 42:93.]

Strictly speaking, theoretical meteorology—except meteorological optics and the study of atmospheric electricity—is nothing but a most complicated hydrodynamic and thermodynamic problem.

The condition existing at a certain point of the atmosphere at any given moment is fully determined by the pressure of the air, its temperature, the amount and character of the moisture contained in a unit of volume, and the direction and velocity of motion.

If these elements are also given for neighboring points of space, or specially the changes that occur in the passage from a given place to another adjoining it, and if one also knows the amount of heat that is added to or abstracted from the particle of the atmosphere under consideration in a unit of time, then one has all the elements that determine the change in the given conditions of the air. If it were possible to unite these quantities in an equation it would be regarded as the fundamental equation of the whole of the theoretical meteorology.

However, even if one should succeed in formulating it, this equation could never attain a practical value, since it would be so involved that a discussion of it would be attended with the greatest difficulties. It would at all events be necessary to subsequently introduce most extensive simplifications and then to disregard first one and then another of the variables occurring in it. Therefore, it has not yet been even attempted to attack the problem from so general a point of view but rather to follow the opposite path. Special cases have been selected in which sometimes one and sometimes another group of the elements above enumerated have been omitted from consideration, and thus the great problem has been resolved into separate problems and general theoretical meteorology has been treated in separate sections.

In this manner the statics and dynamics of the atmosphere, as well as the thermodynamics, have been developed as disconnected studies. This separation is not based on the nature of the subject but is rather only a consequence of the impossibility of attacking the problem in its complete generality. It is precisely because this separation has no natural basis that it introduces many impossibilities, one may even say, dangers. It is necessary, therefore, to closely examine the hypotheses involved in this analysis into separate studies.

This can be most easily done, as it seems to me, by assuming that the general equation mentioned in the beginning as connecting all the elements is really known and has been formulated. With these assumptions we should only have to equate the velocities and accelerations, as also the increase of heat, each to zero in order to convert that equation into the fundamental equation for the static condition of the atmosphere, i. e., into the barometric formula.

Assume, as above, that there is no increase or loss of heat, that the changes of temperature due to compression or expansion need not be taken into account, and that no change of aggregation takes place in the water that is mixed with the air; then when we express the relations between the distribution of pressure, velocity, and acceleration, we should attain the dynamics of the atmosphere in the ordinary sense of the word.

Thus it is seen that the hypotheses made in this case are by no means of so harmless a nature as those which underlie the hypotheses of statics in the atmosphere. The assumption that velocities and accelerations are equal to zero—that is to say, that equilibrium exists—is perfectly admissible; but disregard of the warming by compression is an omission that can not be allowed. It is precisely on account of this and similar assumptions that many investigations into the dynamics of the atmosphere acquire the character of very crude approximations.

It is precisely the enormous difficulties offered by these problems that will oblige us to be content with such approximations for a long time to come; it is, however, important that we should always keep them in mind and if possible estimate the magnitude of the resulting error. The conditions attending the thermodynamic investigations are much more favorable than those attending the study of the dynamics proper of the atmosphere.

In thermodynamics one considers only the relations between pressure, density or specific volume, and moisture, and gain or loss of heat, while the space coordinates of the element of the atmosphere under consideration, as well as its movement, are entirely disregarded. Of these two assumptions the first (neglect of location) is entirely admissible, the latter (neglect of motion) is also admissible on the assumption that the energy of the translatory movement is infinitesimally small in comparison with the amount of heat that is exchanged or converted into work or gained by work, and in the majority of cases to be considered, this second condition is satisfied to a high degree of accuracy.

Hence it follows also that the thermodynamic processes in ascending and descending air currents may be investigated without considering the velocity of the current, because the energy of this latter is exceedingly small in comparison with the work of expansion or compression to be done by the ascent or descent. The results obtained in these investigations hold good, therefore, without considering whether the expansion or compression are actual consequences of an ascent or descent, or whether they are produced by some other cause.

Moreover, this last-named point shows that the division of the general problem into special problems, as made necessary by the complicity or the subdivision of the whole subject into separate studies, also has its own peculiar advantages. Had the problem of the cooling or warming of the ascending and descending currents of air always been regarded from a purely thermodynamic point of view without previously introducing the altitudes into the computation, we could never have fallen into the error of regarding the cooling of the ascending current as a consequence of the work expended in raising the mass of air—work which, in reality, is performed by other air masses that are sinking in other places.

Again, with a purely thermodynamic treatment of these questions it would not have escaped our attention that, in the so-called adiabatic expansion of moist air, from the very beginning of condensation onward we have in general no longer to do with adiabatic changes of condition in the ordinary sense of that term. Properly speaking, adiabatic changes occur only so long as all the water originally present is carried along with the air; as soon as some of the water falls as rain an important change of condition occurs. For whereas in the reversible changes of condition ordinarily considered that occur without gain or loss of heat, the entropy remains unchanged; on the other hand, this is not true in the case of the formation of precipitation by the so-called adiabatic expansion. In the latter case one has to deal with processes that are indeed reversible in the very smallest parts and therefore apart from very insignificant corrections, may also be calculated numerically as such—yet are not reversible when considered as a whole.

It is precisely because moist air exhibits this peculiar behavior when in the condensation stage that the cyclic processes of the atmosphere are so essentially distinct from all others that we have been accustomed to consider. Formerly these peculiarities were never emphasized, but they at once became prominent as soon as the cycles in the ascending and descending currents began to be studied from a purely thermodynamic standpoint.

From these examples it may be seen how well founded is the assertion made above that the analysis of theoretical meteorology into separate studies, although only an expression of our inability, offers also certain advantages.

However, in order to profit by these advantages, it is necessary to make this subdivision as discreetly as possible, and to deduce as completely as possible all the consequences that can be drawn under definite simplifying hypotheses. It is only when this is accomplished that we should try to discover how matters shape up as we gradually begin to take into account the elements that were at first neglected. In this manner connecting bridges are built between the separate branches of our subject. Often this is accomplished, to a certain extent, spontaneously since it suffices to simply observe from a new standpoint the results previously obtained under certain other assumptions.

I will exemplify this by showing how the purely thermodynamic study of the cyclic processes of the atmosphere leads to important conclusions in regard to the general circulation of the atmosphere.

The entire circulation of the atmosphere depends upon great cycles. The air rises at some point, and only after passing through the most varied conditions—after giving and receiving both heat and water—finally descends, and after still further changes of condition begins the process over again. In order to show all these changes clearly and not to lose the guiding thread of these considerations, it is best to represent the changes graphically. This method is as advantageous in the execution of theoretical investigations in order to clearly present the formulæ and trains of thought, as it is in presenting and discussing the material obtained from observation.

In thus utilizing graphic methods one may employ the method or presentation adopted by H. Hertz, or the more general method of Clapeyron, as I myself showed in those days. It must, however, be borne in mind that the curves drawn by the Watts indicator are nothing but diagrams drawn according to the Clapeyron method. Of these two methods of presentation, the former is better adapted for graphic computations, while the latter offers special advantages for theoretical investigations. On the other hand, both methods have one defect which is, indeed, of only very minor fundamental importance, but which may yet be found annoying by those who have had little experience in considerations of this kind.

This defect arises from the fact that in both of these methods the changes of condition experienced by an ascending mass of air are represented by falling curves and those of a descending mass of air by rising curves. This, however, is a difficulty that can easily be overcome by changing the coördinates, as has already been done by Prof. William M. Davis for the Hertzian diagrams.

I will, however, here assume that the more generalized Clapeyron method is employed in its usual form; that is to say, the volume is represented by the abscissæ and the pressure by the ordinates. If we represent a cycle by this method, then, as is well known, the areas of the surfaces inclosed by the diagram are a measure of the work done or consumed. In the extension of this theorem, as used by me, the simple diagram is replaced by the projection of the space-curve representing the change in condition, and hereafter I shall refer to this projection briefly as the diagram.

The question whether in this process work is done or consumed, can be answered at once from the direction along which the curve is traversed. If the change in condition proceeds in such a way that the diagram inclosing the surface is traversed in a clockwise direction, then heat is consumed and by this process work is gained; in the opposite case, work is consumed and heat is gained. Therefore in any atmospheric cycle, e. g., in the exchange of air between cyclone and anticyclone, it suffices to enter in the diagram the actually observed values of the pressure and volume (or what amounts to the same thing, the values of pressure and temperature) in order to at once recognize whether in this process we have to do with a consumption or a gain of heat.

If, for instance, we assume that the atmospheric ascent took place in a summer cyclone in which the temperature is lower than in the attendant anticyclone, then the representative diagram will be traversed in a counter-clockwise direction. In this case, therefore, there is a consumption of work and a gain of heat. But such a process can not possibly contain within itself the germ [or cause] of its existence, since the earth receives energy from without only in the form of heat, which is delivered by the sun at a higher temperature and subsequently radiated from the earth at a lower temperature.

The great atmospheric cycle as conditioned by the general circulation must, therefore, be traversed in an opposite direction to that just described. It must, in fact, be one in which heat is converted into work.

Processes such as that above imagined, although they do seem to correspond to the interchange between cyclone and anticyclone in summer time, are nevertheless never to be explained by the convection theory, but are only conceivable in case the great cycle of the general circulation delivers an excess of mechanical energy in order to develop or sustain smaller processes of the opposite kind.

From this it is clear that even pure thermodynamic considerations may lead to results that are of the greatest importance for the understanding of dynamic processes. Consequently, we recognize that it is a problem of the highest importance to test numerically by means of well-established observations the considerations here set forth. The construction of such diagrams by use of actually observed data would lead to the most far-reaching conclusions.

Of course, it will not be easy to obtain the values for truly closed cycles, since probably only a part of the air that is raised in the cyclone and transported over to the neighboring anticyclone returns again into the same cyclone. Still the classification of temperatures observed at different heights, according to the cyclonal or anticyclonal character of the weather, will be a contribution in this direction.

In this work the data given by observations on mountain tops can, of course, be used only with great caution. The really decisive figures can only be expected from scientific balloon voyages. Among such voyages the most favorable for the investigation of the questions here considered are those in which the ascent takes place in an area of low pressure but the descent in the neighboring anticyclone, or conversely. Then the ascending and descending portions of the curve actually belong together. Such voyages have already been made, but it is of the highest importance that in these voyages numerous observations be obtained, not only during the ascent but also during the descent.

Unfortunately all these investigations suffer from the misfortune that in the atmosphere we have to do, not with masses of air that are subject simply to variations of pressure and gain or loss of heat, but with the fact that mixtures with other masses of air of different temperatures and moistures are always going on at the same time. So long as the amount of moisture remains the same, and we do not leave the dry stage, then the mixture with air of other temperatures acts precisely as if a warming or cooling had occurred, but the case is more complicated when the moisture is variable.

If, in a current of ascending or descending air, the quantity of moisture in a unit mass remains unchanged, then we are justified in supposing that no mixture with other masses of air has taken place. The change in the quantity of moisture, therefore, gives in a certain sense a measure of the degree of mixture with foreign masses of air, but always only under the assumption that it has not left the dry stage.

But these are questions whose thorough explanation would lead us too far. At present it is only necessary to show that from the diagrams of atmospheric cycles constructed from data actually observed, the most important conclusions can be drawn as to the general circulation of the atmosphere. In the construction of these diagrams, however, we need above all a knowledge of the temperature and the moisture at different altitudes in the regions of ascending and descending currents and at different times of the day and the year. Moreover, the investigations should not be confined to processes going on in middle latitudes; they must especially bear upon the great circulation between the region of equatorial calms and the high pressure zones of the "horse" latitudes.

ICE STORMS OF NEW ENGLAND.

A welcome study of the ice storms (verglas; Glatteis) that have been observed over New England and notably at Blue Hill Observatory, Mass., has just come from the pen of Charles F. Brooks.[1]

[1] Brooks, Charles F. The ice storms of New England. Cambridge, 1914. 8 p. 2 pl. 4°. (Harvard University publication.) [Reprinted from Annals, Obs. Harv. Coll., v. 78, pt. 1.]